

Cold Storage for Iowa Apples

Third Progress Report

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COLD STORAGE FOR IOWA APPLES

Third Progress Report

A. Control of Certain Diseases of Cold-stored Apples.

B. Changes of Temperature in Cold-stored Apples.

By W. E. WHITEHOUSE,

Under direction of S. A. Beach and T. J. Maney.

This is the third report* of progress on the investigations pertaining to the holding of apples in storage which have been carried on since 1906 by the pomology section of the Iowa agricultural experiment station**. It covers work which has been in progress during the past five years and deals with several questions:

The temperature of fruit before and after storing; humidity of storage rooms; maturity of fruit when stored; size of apples; wrapping paper used in packing, and methods of storing; the control of certain apple rots which are liable to develop in storage, and the rate of cooling of apples when put into cold storage.

A. CONTROL OF CERTAIN DISEASES OF COLD-STORED APPLES.

DEVELOPMENT AND CONTROL OF APPLE SCALD

Apple scald is one of the serious troubles with which the growers and dealers who store fruit must contend. It is of commercial importance because it injures the appearance of the fruit and consequently lowers its commercial value. It is the cause of serious loss every season to producers and dealers.

Apple scald appears as a brownish discoloration of the skin of the fruit, which, as a rule, does not extend into the flesh, but affects only the epidermal or surface layers of cells that form the color-bearing tissue of the skin. In the first stage of scald the

*"Cold storage for Iowa Grown Apples," Beach and Eustace. Bulletin 108, 1909. "Cold Storage for Iowa Grown Apples," Greene. Bulletin 144, 1913.

**Laurenz Greene, under the direction of S. A. Beach, initiated the lines of experiment by the pomology section which are here reported, while he was chief in pomology. He had charge of installing the experiment station cold storage plant in 1915. After these investigations were relinquished to the junior author in 1916, Mr. Greene continued to give all possible assistance. In 1917, T. J. Maney succeeded to his position. Mr. Greene had the assistance of Robert J. Clark. During the absence of the junior author in the service in the Army in 1917-18, this work was carried forward by H. E. Nichols as experiment station assistant, under the immediate direction of Chief Maney.

skin becomes slightly discolored and turns light brown. As the scald develops further the color becomes darker. In advanced cases, the discoloration penetrates below the skin into the flesh of the fruit.

Our observations are confirmed by those of Brooks and Cooley (5), who state:

In aggravated cases the trouble may extend entirely thru the firmer skin layer into the large isodiametric cells of the pulp. In such case, the flesh becomes soft brown and rot-like and the trouble is often spoken of as "deep scald." In earlier and typical cases of scald the tissue affected is the same as with Jonathan spot, the skin color, however, being a light rather than a dark brown, the areas affected always larger and the demarcation between diseased and healthy tissue less definite than in the case of the Jonathan spot."

Only certain varieties of apples are subject to scald. It develops to a greater degree on green and yellow-colored varieties than on red, and on red varieties it develops principally, if not wholly, upon the green-colored portions of the skin.

Beach and Clark (1) report 33 different varieties of New York apples as liable to scald in storage, including Grimes, Mann, Tolman Sweet, Winter Banana, Yellow Bellflower, Rhode Island Greening, and less often, Green Newtown as the principal green and yellow varieties susceptible to it, and Baldwin, Gano, Missouri Pippin, York Imperial and Winesap, as some of the most susceptible red varieties.

In Iowa, scald is commercially important principally on Grimes, Mammoth Black Twig (ARKANSAS), Sheriff, Northwestern Greening, Willow Twig, and less commonly, on Winesap.

MATERIALS AND METHODS OF INVESTIGATION.

The following scale of percentages was used for rating the different varieties of apples under experiment as to the amount of scald at the time of examination:

Each apple in the box was examined and those which showed scald were rated in one of the three classes, "slight," "medium" or "bad," according to the amount of scalded surface. The range of percentage for these different classes in the case of a green or yellow apple like Grimes or Northwestern Greening, was 0 to 5 pct., slight; 5 to 25 pct., medium; 25 to 75 pct., bad, and in case of partly red apples like Mammoth Black Twig, Sheriff or Winesap, the range was 0 to 4 pct., slight; 4 to 10 pct., medium; 10 to 60 pct., bad. The scale of lower percentage was used in the case of partially-colored apples because, as a rule, only the green or yellow area of a colored apple is subject to scald.

The percentage of scald shows the amount of area scalded as compared to the total area subject to scald. It is evident, for example, with Iowa-grown Mammoth Black Twig, which seldom averages more than 25 pct. green surface, that 10 pct. of scald

would discolor the fruit about as much in proportion to its uncolored surface as would 25 pct. scald on Grimes, a yellow variety on which scald in advanced cases covers the entire apple.

When the scald covers over 25 pct. of the surface, it usually becomes more dense because the small, scattered, scalded spots, which are first noticeable on slightly-scalded apples, blend into a more solid discoloration, making it much more noticeable.

Since apples ranking "slight" or "medium" in amount of scald are not materially injured as to their market value, this classification is chiefly of interest in noting for the purposes of the experiment the extent to which scald has developed.

In cases where the total number of scalded apples is used as the basis of comparison among different boxes, these totals do not necessarily show the actual difference in scald for the reason that under "total scald" are included all of the "slight," "medium" and "bad" classes. Thus one box may contain a large number of slightly-scalded apples and only a few badly scalded, while another may contain a smaller number of slightly-scalded apples and a correspondingly larger number of badly scalded, and both boxes have the same number or the same percentage of "total scald." In such a case, there would be a difference in the actual amount of scald present which could not be shown by using "total scald" as the basis of comparison.

Take for example, two boxes, each containing 125 apples, and let one rate 12 pct. slight, 32 pct. medium, and 52 pct. bad scald, while the other rates 52 pct. slight, 32 pct. medium, and 12 pct. bad. Each box would then rate a total of 96 percent of the fruit scalded.

Assuming that the first box is a box of Grimes, and the mean percentage for each class $2\frac{1}{2}$ pct. for slight, $12\frac{1}{2}$ pct. for medium, and $37\frac{1}{2}$ pct. for bad; the second, a box of Mammoth Black Twig, the mean percentages 2 pct. for slight, 5 pct. for medium, and 30 pct. for bad, the actual scald would be estimated as follows for the two boxes, respectively:

	Slight	Medium	Bad	Total	Average Per- centage
Grimes, number.....	15	40	65	120	-----
Grimes, aggregate percentage.....	37.5	500	2437.5	2975	24.79
Mammoth Black Twig, number.....	65	40	15	120	-----
Mammoth Black Twig, aggregate percentage.....	130	200	450	780	6.5

STORAGE AND APPARATUS.

The apple cold-storage investigations were carried on by the pomology section prior to the season of 1915-16, in commercial

cold storage plants in different parts of the state. Beginning with 1915-16, this work has been done in the cold storage plant of the pomology section at Iowa State College.

Accurate records of the temperatures maintained in these rooms were kept. A thermograph was used which recorded the temperature for 30 days, without rewinding. This type of thermograph is shown in fig. 1. The apples were examined twice during the storage season. At each examination the boxes were removed to a lighter room of about 60°F. temperature, where they were unpacked, examined, rewrapped, packed and immediately put back into their respective storage rooms. At no time were the apples subjected to the higher temperature outside the storage for more than two hours, which was not long enough to affect materially the temperature of the fruit.

All the fruit used was grown and packed at the state experiment orchard, Council Bluffs, Iowa. This orchard is growing on a Missouri loess formation, the type of soil on which such varieties of apples as Jonathan and Grimes reach a very high degree of perfection. The fruit was shipped to Ames at once and immediately stored in the pomology section cold storage plant in accordance with the respective requirements of the plan of the experiment.

During the season of 1915-16, Grimes, Sheriff, and Mammoth Black Twig (ARKANSAS) apples were stored in three rooms held at 32°F., 36°F., and 40°F., respectively. The apples in each box were divided into four lots: those free from scald, those slightly scalded, those of medium scald, and those badly scalded.

During the season of 1916-17 and 1917-18, only two storage temperatures were used, 32°F. and 40°F. Two rooms were held at each of these temperatures, one with high and the other with low relative humidity.

During the season of 1917-18, a fifth storage room was also included in the experiment. In this room the temperature was fluctuated every two weeks between 32°F. and 40°F.

In each case, each variety was examined twice during the season, usually in December or January, and again in February; the later-keeping varieties received a third examination in March or April.

EXPERIMENTS INCLUDE COMMERCIAL QUANTITIES OF FRUIT.

It is worthy of note that these investigations are based on the records of apples stored in commercial quantities. In no case was there less than one box and in the majority of the investigations from 10 to 50 boxes were under experiment. The number of apples ranged from 125 to 188 per box.

The experiments and observations demonstrate that there is a variation in the amount of scald found in the different boxes of

any one lot of apples, notwithstanding the fact that they have been grown, picked, packed, and stored under conditions as similar as it was possible to make them. It is clear, therefore, that in investigations of this nature the larger the number of apples under experiment, the more nearly it is possible to secure accurate results and reach reliable conclusions.

The following statement gives the number of boxes of each variety used in the temperature investigations:

NUMBER OF BOXES OF APPLES UNDER EXPERIMENT.

	1915-16	1916-17	1917-18
Grimes -----	32	50	59
Mammoth Black Twig -----	12	21	21
Sheriff -----	9	14	21

The total number of apples under test in the three-year period at the minimum rating of 125 per box, was 5,500 Sheriff, 6,750 Mammoth Black Twig, and 17,625 Grimes.

EFFECT OF TEMPERATURE ON SCALD.

The relation of temperature to the development of apple scald has been studied by various investigators.

Powell and Fulton (8) working with York Imperial, Rhode Island Greening and Sutton apples, found that immediate storage

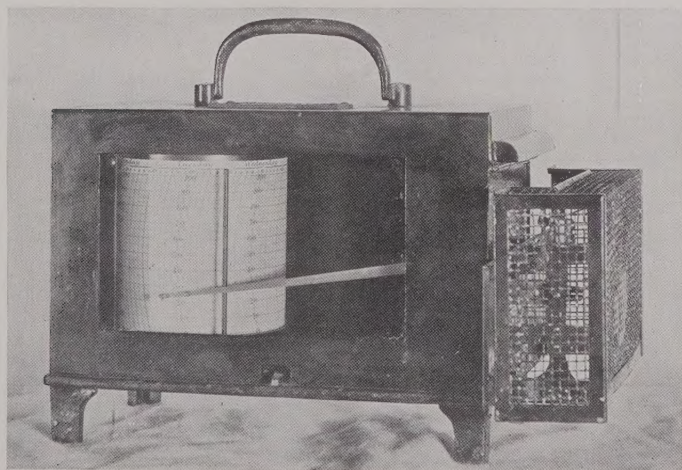


Fig. 1. Type of self recording thermograph used in the cold storage experiments.

at 32°F. resulted in much less scalding than did immediate storage at a higher temperature of 36°F. It is inferred that this fruit was hard-ripe and well-colored when stored.

Greene (7) in previously reported work at the Iowa station found that under the conditions of his experiments, Grimes and Winesap developed less scald and Northwestern Greening more, in cellar storage than in cold storage. The fruit was picked at the normal picking time for the variety.

Our later observations have shown that results the opposite of these obtain with immature as compared with mature fruit of Grimes.

Ramsey, McKay, Markell and Bird (10) report slightly less scald developing on apples at 32°F. than at 35°F., or than in common storage. Since it is not otherwise stated, it is inferred that these apples were picked in prime condition for the commercial pack.

Brooks and Cooley (5) in a series of laboratory experiments found scald starting to develop sooner at 20°C. (68°F.) than at 15°C. (59°F.), with a marked contrast between temperatures of 10°C. (50°F.) and 15°C. (59°F.) in favor of apples stored at 10°C. (50°F.). Scald developed rapidly at 10°C. (50°F.) during the third month of storage, whereas it was four months before it appeared at 5°C. (41°F.) and five months at 0°C. (32°F.). The whole series of experiments was consistent in showing that an increase in temperature was accompanied by an increase in rate of scald up to an optimum of 15°C. (59°F.), or 20°C. (68°F.). The critical period for scald development appeared about a month earlier with each five degree rise in temperature. Apples stored at fluctuating temperature developed but little, if any more scald, than similar apples at an average constant temperature. The authors give the date of picking but not the condition. With no statement to the contrary it may be assumed that the fruit was picked in prime condition for storing.

Table I gives a comparison for three successive years of the total amount of scald developed on these three varieties, grown in the same orchard and held in cold storage.

Differences in seasonal conditions in the ripening of the fruit and in the length of time between the examinations of the stored apples in different seasons, and the fact that the examinations were not all made by the same person thruout the three-year period, make it evident that no rigid comparison can be made as to the amount of scald developing on the same variety in different seasons. In each season rigid comparisons can be made between different lots of the same variety held under the different conditions of the experiment.

The data show that in all cases but one, more scald developed at

the higher temperatures. A comparison of the "bad" scald shows decided differences in the amount developing at the different temperatures. In examining the apples it was found that only those badly scalded were commercially unsalable as first-class fruit. From the standpoint of the practical storage man, therefore, the table showing the amount of bad scald is of most interest. These results correspond with those of other investigators and confirm the statement that a temperature not higher than 32°F. is best for storing apples, as far as the development of apple scald in storage is concerned.

In 1917-18 six boxes each of Grimes were stored at 32°F. and 40°F. These apples were, in the writer's judgment, at a proper maturity for storage. Four boxes were held in a room which was fluctuated between 32°F. and 40°F., that is to say, the temperature was held for two weeks at 32°F., then for two weeks at 40°F., then for two weeks at 32°F., and so on until the end of the storage period of 28 weeks.

The amount of bad scald developing on Grimes and Mammoth Black Twig during the 1917-18 storage season is, shown graphically in figs. 2 and 3. At the end of 13 weeks Grimes at 32°F. were practically unhurt commercially, but at the end of 18½ weeks almost 50 pct. were commercially unsalable as a No. 1 grade, altho they might be disposed of under a lower grade.

Mammoth Black Twig, held at 32°F. for 20 weeks, showed only 15 pct. bad scald, bringing this variety to March 1 in good condition in regard to scald. It should not be held commercially later than this date, but put on the market immediately.

On the average, the apples stored in a temperature fluctuating between 32°F. and 40°F. contained less scald than those stored at 40°F., and a little more than those stored at 32°F.

The question as to whether fluctuating the temperature of the storage room after the fruit has been cooled down to 32°F. can

TABLE I. EFFECT OF TEMPERATURE ON APPLE SCALD.

Variety	Percent of total scald				Percent of bad scald		
	Date Examined	40°F.	36°F.	32°F.	40°F.	36°F.	32°F.
Grimes -----	6- 1-16	55.5	38.7	19.4			
	2- 1-17	79.9		6.4	34.0		0.05
	2-16-18	98.5		59.3	81.9		33.0
Sheriff -----	3-18-16	87.6	82.8	67.0	49.2	43.6	20.5
	3-27-17	81.0		18.5	36.4		0.33
	4-23-18	53.1		12.1	16.7		0.5
Mammoth Black Twig -----	3-22-16	74.2	63.9	77.9	3.8	7.0	53.5
	4-30-17	97.0		91.7	82.3		75.3
	4-30-18	99.3		95.4	98.8		83.2

be used to practical advantage by the cold-storage man as a method of saving fuel, is a matter for further investigation.

EFFECT OF HUMIDITY ON SCALD.

The effect of humidity on the development of apple scald was studied during the seasons of 1916-17 and 1917-18. High and low humidities were maintained in storage rooms held at temperatures of 32°F. and 40°F., respectively. The rooms with a low relative humidity were kept dry by the use of calcium chloride spread on shallow pans so that the moisture would be absorbed readily. The pans were changed as often as necessary. The relative humidity ran from 60 to 70 pct., a careful record being obtained by means of a 30-day self-recording hygrometer (see fig. 4). The moisture content of the air in the rooms of high humidity was maintained by the use of a large carbon electric light bulb inserted into a wire basket which was covered with cheese cloth. This basket was placed in a pail of water so that the electrical bulb was partly immersed, causing the water to heat sufficiently to vaporize rapidly. The cheese cloth acted as a wick and gave a greater evaporating surface. In this manner the relative humidity was kept between 80 and 90 pct. A record sheet used in the thermograph and one used in the hygograph are shown in fig.

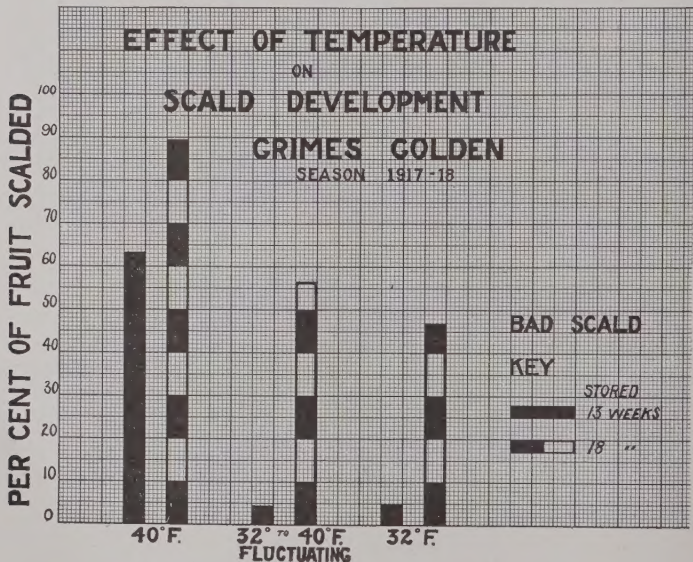


Fig. 2. Grimes. Effect of temperature on scald in storage.

5. The upper sheet shows the relative humidity record and the lower sheet the temperature record for one month.

It must be remembered that at any specified temperature relative humidity expresses the relative amount of moisture in the air, at that temperature only. The amount of moisture that can exist as vapor in the air depends on the temperature. At a low temperature, even a high relative humidity represents a very small amount of vapor actually in the air, while a low relative humidity at a high temperature may represent a considerably larger amount. In the rooms in which relative humidity was kept high, the outside of the boxes was damp, while those in the drier rooms were dry.

A comparison was made between Grimes and Mammoth Black Twig apples stored at 32°F., both in rooms of high and low relative humidity, and the same varieties stored at 40°F. in both high and low relative humidity. The percentages given in tables II and III represent the results of examinations made on 36 boxes of Grimes and 10 boxes of Mammoth Black Twig during the season of 1916-17, and 30 boxes of Grimes and 13 boxes of Mammoth Black Twig during the season of 1917-18. These apples represented various grades as to size. They were wrapped in ordinary apple-wrapping paper and packed in boxes.

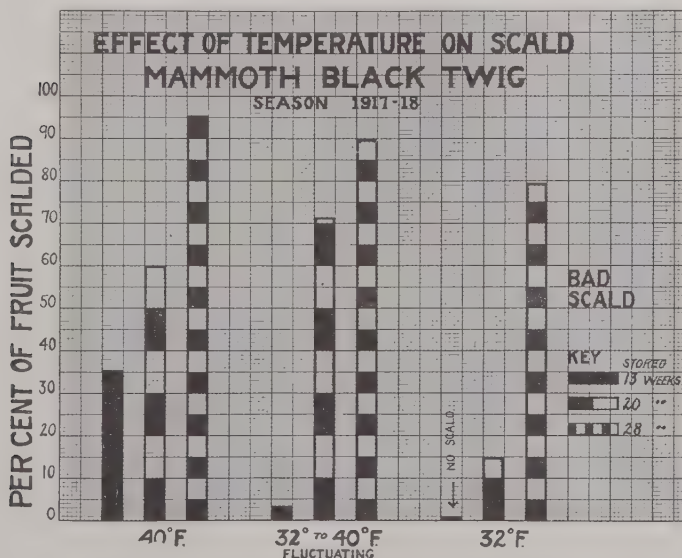


Fig. 3. Mammoth Black Twig. Effect of temperature on scald in storage.

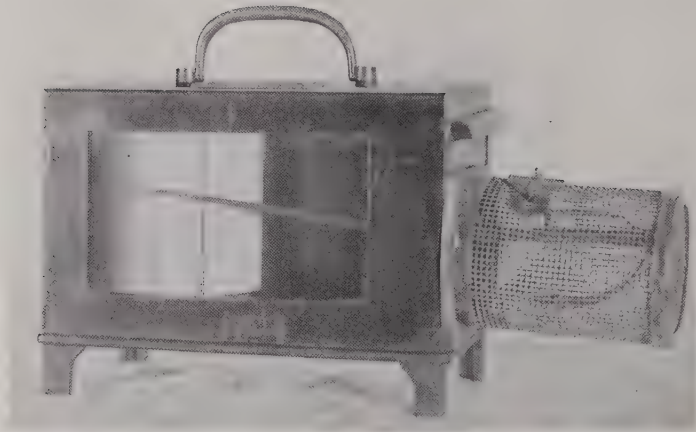


Fig. 4. Type of self-recording hygrometer used in the cold storage experiments.

The percentages recorded for Mammoth Black Twig apples wrapped in wax paper were obtained from 10 boxes of apples.

These tables show the rating for bad scald only. The apples stored in the rooms containing a high humidity were at one time more badly affected on the average, but at the end of the storage season this difference was less marked because the apples had then scalded badly under both conditions of humidity. This was evident when the last examinations were made the latter part of April.

Two sets of four boxes each of Mammoth Black Twig, one set wrapped in paraffine paper, the other in ordinary apple wraps of tissue, were stored October 16, 1917, each under high and low humidities, and at 32°F. and 40°F., respectively. On January 17, 1918, no scald had developed on those in ordinary wraps at 32°F., under either high or low humidity. The apples in the dry room at 40°F. had 14.3 pct. of bad scald as compared with 35.3 pct. in the moist room at 40°F. The other set in wax paper developed no scald at 32°F., under either high or low humidity and at 40°F. only 0.6 pct. bad scald in the dry room as compared to 32.6 pct. in the moist room.

From these tests it appears that while the degree of humidity bears some relation to the development of apple scald, the degree of temperature has a greater influence. This would naturally be expected since temperature has more effect than humidity upon the processes of maturing and physiological decay of the fruit.

These results are confirmed by the work of Brooks and Cooley (5), who found less scald on apples stored under comparatively dry, than under moist conditions. At 0°C. (32°F.) there was but

TABLE II. PERCENTAGE BAD SCALD UNDER DIFFERENT TEMPERATURE AND HUMIDITY CONDITIONS, 1916-17.

MAMMOTH BLACK TWIG					
		Relative Humidity Percent			
		Tissue Wrap		Wax Wrap	
Days	Temp.	80-90	60-70	80-90	60-70
102	40°F.	50.8	44.2	43.6	24.8
155	40°F.	63.5	59.5	48.9	52.7
198	40°F.	88.9	80.9	66.9	78.0
102	32°F.	4.3	20.6	24.8	15.6
155	32°F.	56.2	56.2	52.7	60.0
198	32°F.	84.6	66.0	78.0	65.6

TABLE III. PERCENTAGE BAD SCALD UNDER DIFFERENT TEMPERATURE AND HUMIDITY CONDITIONS, 1917-18.

MAMMOTH BLACK TWIG					
		Relative Humidity Percent			
		Tissue Wrap		Wax Wrap	
Days	Temp.	75-85	60-70	75-85	60-70
93	40°F.	39.5	8.5	32.6	0.3
141	40°F.	69.9	71.7	14.7	51.6
189	40°F.	95.3	92.6	93.4	82.9
93	32°F.	0	0	0	0
141	32°F.	27.0	15.3	30.1	5.3
189	32°F.	85.1	79.4	84.9	76.6

GRIMES

119	40°F.	47.4	26.0	-----	-----
119	32°F.	1.6	0.0	-----	-----

GRIMES

130	40°F.	89.9	74.0	-----	-----
130	32°F.	38.7	19.5	-----	-----

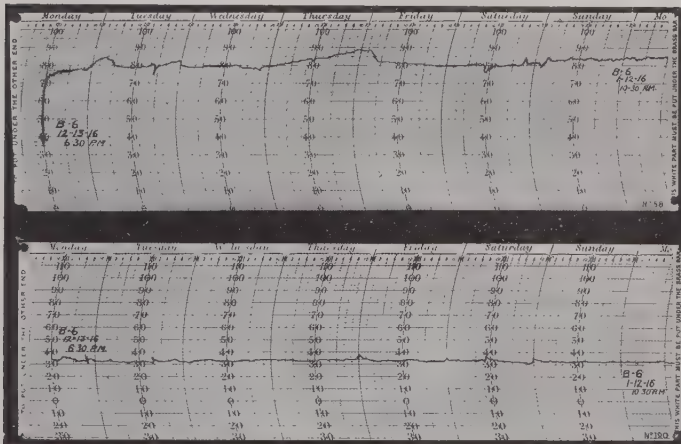


Fig. 5. Specimen record sheets of self-recording thermographs and hygrometers used in the cold storage experiments.

little more scald on apples stored in moist chambers than on those stored in open containers while at 5°C. (41°F.) the contrast was extreme, all the apples in the moist chambers being badly scalded.

In a later publication, Brooks, Cooley and Fisher (6) report :

It has been found possible to store apples in air saturated with water vapor without the development of scald. In several different experiments scald was considerably reduced by decreasing the humidity, but the beneficial effects were apparently not entirely due to the decreased moisture in the air. * * *

It does not seem, however, that high humidity can be the primary cause of the disease (scald), for in no case was scald entirely prevented by dryness, and in every case where the air was stirred, the disease was practically eliminated, even in the presence of the highest humidities. The withering of the apples in the dry air makes this method of partial prevention an impractical one, and the fact that the disease can be prevented without drying naturally raises the question whether the beneficial effects noted from the use of moisture-absorbing agents may not be at least partially due to their power to absorb some substance other than water, or to the fact that evaporation of the water assists in the elimination of some distinctly harmful substance.

The drier the storage rooms, the less the scald:

Many storage experts have suggested that the lack of humidity in storage rooms is one of the probable causes for the development of scald. Our investigations indicate that the drier rooms are more suitable, as far as scald prevention is concerned.

In larger storage rooms, such as are found in our commercial cold-storage houses, the lack of humidity may be much more extreme, and the benefits of increasing the humidity more noticeable. Further observations on this point are desirable.

Shrivelling of fruit and relative humidity:

The real danger with low relative humidity is that shrinkage and shrivelling of fruit may result. It has been found in this work that under the conditions of the experiments but very little shrinkage has occurred, even under the low humidities. When the apples were shrivelling and losing weight, it was found to be directly attributable to some other factor, such as a skin puncture, which should have been eliminated in packing the fruit.

Beach and Clark (1) in a study of the keeping qualities of New York apples found that shrivelling was more severe in the russet apples, such as Roxbury Russet and English Russet. Apples of this type keep best in storage containing a high relative humidity.

The shrinkage on apples in commercial storage houses cannot be laid entirely to the condition of the humidity in the storage room, but probably, for the most part, can be traced back to the amount of care and attention given the fruit at the time of har-

vest and packing. Skin breaks, spray injury, stings, and worm holes are largely responsible for shrivelling of apples in storage. This is one of the reasons why it is important to store only fruit which has a perfectly sound skin.

Bell jar experiment:

The effect of humidity on scald was studied under more exact conditions during the season of 1916-17 in an experiment in which the fruit was kept under bell jars in a room held at a constant temperature of 32°F. The factors of changes in aeration and fluctuations in humidity due to opening and closing the doors of the cold-storage rooms were thus eliminated.

Three large bell jars were used, in each of which were put Mammoth Black Twig, Jonathan, Grimes, and Sheriff apples.

From four to 12 apples of each variety were put under each jar. The fruit was selected with great care so as to make the different lots as similar as possible in respect to uniformity in size, color, soundness, and freedom from scald.

The humidity in the jars was checked at frequent intervals. The method which was used in doing this is a modification of the Shreve (11) dewpoint method. A photograph of one of the bell jars and this apparatus for determining the dewpoint, is shown in fig. 6. The apparatus consists of a metal cylinder, the face of which is highly-polished nickel. Two glass tubes and a certified thermometer are fastened into the cylinder and held in place in the neck of the bell jar by means of a rubber stopper. Ether is conducted thru the glass tubing into the cylinder. With the aid of a small rubber bulb similar to that used on a camera, air is forced down one tube over the ether, and out the other tube, and conducted thru a rubber tube about three feet long, before escaping into the outside air. The temperature is lowered when the air is forced over the ether and condensation occurs on the highly polished outside sur-

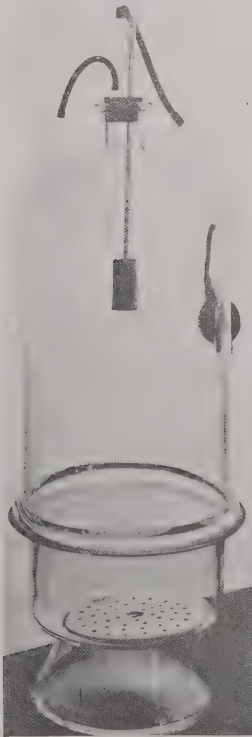


Fig. 6. Bell jar and apparatus for determining dew point in humidity experiments.

face of the cylinder. The dewpoint of the air inside the jar is readily determined by observing the temperature inside the cylinder before the air is forced over the ether and after condensation occurs.

The records show that the relative humidity did not vary more than 4 pct. in any one of the jars during the entire period of the experiment.

Each jar was held at a different percentage of relative humidity. The humidity was controlled by the use of varying amounts of sulphuric acid and water as shown by the following table:

	H ₂ SO ₄	Water
Jar 1, 50 pct. relative humidity -----	52.6 cc.	47.4 cc.
Jar 2, 75 pct. relative humidity -----	96.3 cc.	73.7 cc.
Jar 3, 95 pct. relative humidity -----	5.3 cc.	94.7 cc.

The experiment was started February 20, 1917, and closed May 11, 1918. At the end of the experiment each jar was tested for the amount of carbon dioxide or carbonic acid gas [CO₂] present. Jar 1 with 50 pct. relative humidity contained 34.2 pct., jar 2 with 75 pct. relative humidity 26.3 pct., and jar 3 with 95 pct. relative humidity, 30 pct. CO₂. The amount of CO₂ normally present in the air is less than 1 pct. This increase of CO₂ in the jars is due to the respiration of the apples.

Altho this experiment is not on a scale extensive enough to permit drawing definite general conclusions, it is interesting to note that under the conditions as stated there was less respiration at 95 pct. than at 50 pct., relative humidity. At the end of the experiment the apples in the jars containing 75 and 95 pct. relative humidity were quite badly broken down, while those at 50 pct. were still fairly well preserved.

One month after the experiment was started, the apples at 50 pct. humidity were much better in appearance than those in either of the other two jars; this relative condition held thruout the entire length of the experiment. Less scald developed on the Grimes, Sheriff, and Mammoth Black Twig in the jar containing 50 pct. relative humidity than in either of the other two jars. Also there was less scald on these varieties at 75 pct. than at 95 pct. relative humidity.

In all of the jars, the apples eventually broke down, but the breakdown was much worse in the higher humidities. At the end of the experiment none of the apples in any of the jars was fit to eat.

This experiment confirms the results of our previously mentioned investigations and gives additional evidence that, other things being equal, apples keep best in low humidities.

This experiment also shows the value of aeration. These fruits that were kept in bell jars in unchanged air for three months, lost flavor and broke down, while similar apples kept in the adjoining storage rooms at the same temperature but where there was more or less circulation of air, remained in good condition long afterwards.

EFFECT OF APPLE WRAPS ON SCALD.

Greene (7) in earlier investigations at this station found that apples wrapped in paper matured more slowly, and did not scald as quickly as those unwrapped.

The results of the past five years' work are given in table IV. The figures show the averages of all the apples examined.

During the seasons 1913-14 and 1914-15, wrapped apples were compared with unwrapped apples. The results in practically every case show less scald on wrapped than on corresponding unwrapped apples.

In the later investigation comparisons were made between apples wrapped in ordinary wraps and those wrapped in a wax or

TABLE IV. EFFECT OF WRAPS ON SCALD.

			1913-14		1914-15		1915-16		1916-17		1917-18	
Variety	Temp. Fahr.	Scald Degree	No Wrap	No Wrap	No Wrap	No Wrap	Wax	Tis- sue	Wax	Tis- sue	Wax	Tis- sue
Grimes	32°	Bad Total					45.1	37.2	3.0 7.3	8.0 10.8	45.0 94.0	32.9 95.0
Mammoth Black Twig	32°	Bad Total							56.3 86.4	58.8 91.4	21.8 78.7	29.7 80.1
Sheriff	32°	Total	49.6	37.0	34.4	21.6						
Winesap	32°	Total	4.1	4.9	22.5	17.1						
Grimes	40°	Bad Total							19.9 54.2	47.4 89.8	76.1 100.0	61.3 99.0
Mammoth Black Twig	40°	Bad Total							63.8 73.0	61.0 78.0	39.3 89.8	70.8 95.1
Sheriff	40°	Total	72.7	66.4							1.4	12.1
Winesap	40°	Total	29.8	25.6	41.5	34.0						

paraffine paper, which was practically air tight. This line of work has now been carried on for three seasons.

The results in table IV show that apples wrapped in wax paper developed slightly less scald than those apples wrapped in ordinary apple wrappers.

Brooks, Cooley and Fisher (6), who have made more extended investigations along this line, report:

Ordinary apple wrappers have had no effect on apple scald, and paraffine wrappers but little; but wrappers soaked in various mixtures of olive oil, cocoa butter, vaseline, or beeswax have entirely prevented apple scald.

LOCATION IN PACKAGE AND SCALD.

Observations were made to determine whether scald developed to a greater extent in the middle of the box than in the outer layers. It was found that just as much scald developed in one part of the box as in another.

SIZE OF FRUIT AND SCALD.

The apples used in this part of the experiments were sized by an apple grader, packed in boxes according to their respective sizes and stored under similar conditions. The development of scald on each of the different grades was recorded. The data thus obtained indicate that the size of fruit, in itself, has no definite relation to the development of scald.

Table V shows the records for Grimes for the four seasons of 1915 to 1918, inclusive. Unfortunately, records of the different ratings of slight, medium, and bad scald were taken for only a part of this period. The records here given are therefore for total scald only. The grade as to size is indicated by the number of apples per box.

TABLE V. EFFECT OF SIZE ON DEVELOPMENT OF SCALD.

			Percent Total Scald					
			125 Size	138 Size	150 Size	163 Size	175 Size	200 Size
1914-15	32° F.			24.0	31.6		22.6	26.2
1915-16	32° F.			14.3	14.6	29.7	23.6	34.8
1916-17	32° F.	7.47			6.0		4.5	
1917-18	32° F.	3.0	1.5		2.5	4.0	1.5	4.0
1917-18	40° F.	97.4			96.9		91.1	

It is true that in the case of Grimes, Northwestern Greening, and Mammoth Black Twig, the records indicate a slight difference in favor of the smaller size, but the results are variable and it is believed that the differences observed are not significant of a greater susceptibility to scald in the larger sizes.

The question arises as to the extent of the differences in degree of maturity between large and small apples of the same variety picked at the same time. Undoubtedly there are some differences of this kind and in the case of Northwestern Greening, especially, they may be sufficient to account fully for all the variations above recorded.

EFFECT OF MATURITY AND DELAYED STORAGE ON SCALD.

During the growing season the apple stores up food material, consisting mainly of starches and acids with smaller amounts of other compounds. As the fruit approaches maturity and until it becomes fully ripe and the processes of physiological decay begin, the starches are changing to sugars and the sugars and acids are gradually breaking up into simpler compounds. It should be remembered that when the apple is picked from the tree it is a living unit, the same as a leaf or flower would be, but is different in that it can live much longer after being separated from the tree than the more perishable blossoms and foliage. The object of storage is to furnish favorable conditions for continuing the life of the apple and postponing its final breakdown. Low temperatures which are at about the freezing point are the most effective in checking the rapidity of these changes.

The practice of placing fruit in storage immediately after picking is therefore generally advised.

It is interesting to note in this connection the results of the thoro study of changes in the chemical composition of apples made by Bigelow, Gore and Howard (3). They have found that the principal changes are as follows:

1. A slight but continuous decrease in the total acidity calculated as malic acid.
2. A gradual decrease in sucrose.
3. A gradual increase at first, followed by a later slight decrease, in invert sugar and total carbohydrates calculated as invert sugar.
4. The disappearance of starch early in the ripening process.

The influence of maturity and delayed storage on the development of scald has been studied by several investigators in the past few years.

Powell and Fulton (8) were the first to demonstrate that when the apple crop is picked before it is mature the fruit is more susceptible to scald than when it is picked at prime maturity for harvesting.

Brooks and Cooley (5) found that green, immature apples which were put into storage immediately after picking, developed scald later than more mature apples from the same tree, but when the scald on the immature apples did appear, it developed more rapidly and to a larger degree.

Ramsey, McKay, Markell, and Bird (10) found much less scald developing on apples stored immediately than on those delayed for two weeks after picking before storing. It is inferred that the fruit was picked at the commercial picking season for the variety. They also found that immature apples developed more scald than mature fruits.

Greene (7), at the Iowa agricultural experiment station on September 29, 1913, picked and packed two similar lots of somewhat immature Grimes apples. One lot was placed immediately in cold storage at 32°F. and the other held in the packing shed at the state experiment orchard. October 29, one month later, the apples which had been held at the packing shed were placed in cold storage. Examination made April 14, 1914, showed that the apples which were held at the orchard for one month before storing had noticeably much less scald than those which were stored immediately after picking. It is evident that they had an opportunity to advance much more rapidly in maturing during that period than did the corresponding lot of fruit which was put immediately into cold storage.

As will be shown later, the results would have been different had both lots of the apples been properly matured on the tree before picking and storing.

A study of the behavior of Mammoth Black Twig, which seldom, if ever, reach prime development under Iowa conditions, reveals the fact that this variety as grown in Iowa scalds more or less severely under all storage conditions. It is probable that further study would show this same condition to be characteristic of certain other varieties grown in Iowa which are not as well adapted to Iowa conditions as to those further south.

Iowa-grown Mammoth Black Twig scald almost as badly at 30°F. as at 40°F. (see table I). They are always more or less immature at picking time, even tho picked late in the season as compared with other varieties in the same orchard, and they must necessarily go into storage somewhat immature. During 1916, 53 pct. of the Mammoth Black Twig apples stored at 32°F. were badly scalded, while apples from the same lot stored at 40°F. had only 3.8 pct. of bad scald. It should be noted that altho a large amount of the apples at 40°F. were starting to scald by March 22d, the scald had not yet developed to any considerable degree. Note that with the crops of 1917 and 1918, however, different results were obtained, for more scald developed at 40°F. than at 32°F. This shows that variable results are to be expected in cold-storing Iowa-grown Mammoth Black Twig in different seasons because of the difference in the degree of maturity of the fruit at picking time. A possible explanation is that the enzymatic action which occurs in the ripening process of the apple, is not retarded as much at 40°F. as it is at 32°F.

The apples in a temperature of 40°F. have an opportunity to attain greater maturity, and consequently if they happen to be immature scald less, even tho the temperature of 40°F. is generally regarded as more favorable to scald development.

Scald development is closely correlated with the factors of maturity and length of life of apples in storage as is shown in the case of the Grimes. On January 4, 1918, all the Grimes stored at 32°F. contained only 2.8 pct. badly-scalded apples, practically unhurt from the marketable standpoint, yet on February 6, 1918, one month later, this same lot of apples under a temperature of 32°F. contained 33 pct. of badly-scalded apples.

Ordinarily the commercial cold-storage period of the Grimes should not be extended later than January. When held later than this, scald develops more rapidly and, generally speaking, the apples also tend to break down more quickly when removed from storage. Owing to such facts it has become the established custom of the trade not to handle certain varieties beyond a certain season. For example, Fameuse, Grimes, Jonathan, and Winesap each have their particular season with the trade, and most dealers do not care to handle them out of their trade season, even tho it is possible to hold them longer in storage in apparently good condition.

A study of immediate and delayed storage as related to the development of scald was made with Sheriff and Mammoth Black Twig apples in three different years. Three pickings were made, the first about two weeks before the normal picking season for the variety, the second at the normal picking season, and the third about two weeks after the second. In each case the apples were packed immediately after picking, and one-half of them were left in the packing shed for two to four weeks, after which they were put into cold storage. The other half were placed in cold storage immediately.

The regular examination for scald in this test was made each season in March. Later in the season all these varieties start to scald so badly in storage that they deteriorate quickly in value.

Mammoth Black Twig apples do not reach proper maturity for picking till very late; Sheriff is intermediate between Jonathan and Mammoth Black Twig. After October 10, under South-western Iowa conditions, there is danger of bad freezes; in fact, during the fall of 1917 the temperature dropped to 24°F. on October 12 and to 21°F. on October 19. To avoid danger of freezing, these later-maturing varieties must of necessity be picked while still somewhat immature. When packed and stored at once, it has been observed that they scald quite badly in storage. When the fruit is allowed to stand in the higher temperatures of the packing shed for several weeks before going into cold storage, it rapidly matures and as a result scalds less than when put immediately in cold storage.

TABLE VI. EFFECT OF DATE OF PICKING AND DELAYED STORAGE ON SCALD. TEMPERATURE UNIFORM AT 32°F.

SHERIFF. Percent of Total Scald.						
Picking Season						
Year	Early		Normal		Late	
	Immedi- ately	Delayed	Immedi- ately	Delayed	Immedi- ately	Delayed
1913-14 -----	97.0	72.0	71.0	43.8	49.4	59.1
1914-15 -----	75.6	10.8	25.0	3.2	-----	10.0
1916-17 -----	77.1	31.8	18.7	63.2	10.0	-----
SHERIFF. Percent of Bad Scald.						
1916-17 -----	43.0	6.15	0.0	24.6	0.0	-----
MAMMOTH BLACK TWIG. Percent of Total Scald.						
1913-14 -----	41.2	44.6	41.3	13.8	10.4	2.2
1914-15 -----	100.0	84.0	87.0	95.0	24.0	-----
1916-17 -----	98.7	98.2	97.2	99.0	-----	-----
MAMMOTH BLACK TWIG. Percent of Bad Scald.						
1916-17 -----	77.5	73.0	58.0	84.7	-----	-----

Table VI gives the results of the observations on Sheriff and Mammoth Black Twig with the crops of 1913, 1914, and 1916.

SHERIFF DELAYED STORAGE.

Note under "Sheriff Percent of Bad Scald," in table VI, that during 1916, 43 pct. of the Sheriff apples picked early and stored immediately in cold storage at a temperature of 32°F. had scalded badly by March, whereas a similar lot of apples picked at the same time, but held at the packing shed for a period of four weeks at a temperature of 70° to 80°F. before cold storing, had in the same period developed only 6.15 pct. of bad scald.

With the corresponding two lots of Sheriff apples picked at the normal picking season, one cold stored immediately, and the other held at the packing shed for four weeks and then put into cold storage, the records show that no bad scald developed on the apples stored immediately, whereas 24.6 pct. of bad scald developed on those apples held at the packing shed for four weeks before storing. It is evident that the delayed-storage lot became over-mature before going into cold storage. This again clearly

demonstrates that there is a proper stage of maturity which apples must attain before being stored at low temperatures if the development of scald is to be successfully retarded.

Sheriff apples stored in the fall of 1917 showed a higher degree of color and maturity than those of the preceding three seasons. At the February examination no scald had developed on the 17 boxes of Sheriff stored at 32°F. and on April 23, 1918, an average of only 6.91 pct. of scald, while from 40 to 70 pct. had developed during the corresponding periods in the seasons of 1915-16 and 1916-17.

Sheriff windfalls without bruises were stored October 13, 1913, as an additional test. These apples developed the least amount of scald of any lot that year. Windfalls would naturally be mature, for late in the growing season when an apple drops on the ground it continues its life process of respiration, and becomes mature and ripe. These windfalls developed only 17.8 pct. of scald by March 3, whereas Sheriff apples picked and stored October 13, 1913, had developed 49 pct. of scald.

WINESAP. DELAYED STORAGE.

Winesap apples picked September 23, 1914, two weeks before the normal picking season, and stored immediately at 33°F. showed more scald by April 12 than those picked a week later. This held true for both wrapped and unwrapped apples. Delaying the storage a month reduced the amount of scald from 5 to 20 pct.

GRIMES. DELAYED STORAGE.

Examination of Grimes apples held in the packing shed for two to four weeks after picking before placing them in storage, showed that the solid green color, normal at picking time, had turned to a yellowish green, indicating ripening of the fruit. Fig. 7 shows Grimes of immediate and one of delayed storage, taken January 10, 1918. These specimens are fairly typical of the fruit used in this investigation. The apples delayed at the packing shed before storing ("A" is typical of this lot), were practically free from scald and of a nice yellow color, while the apples stored immediately after picking ("B" is typical of this lot), were greener and had started to scald slightly over part of the surface. The greener apples are usually immature and prove more susceptible to scald.

GENERAL DISCUSSION OF EFFECT OF MATURITY AND DELAYED STORAGE.

The foregoing results and those of other investigations noted, lead to the conclusion that the fruit should, if possible, reach proper maturity for cold storage before being picked and should then be put immediately into cold storage.

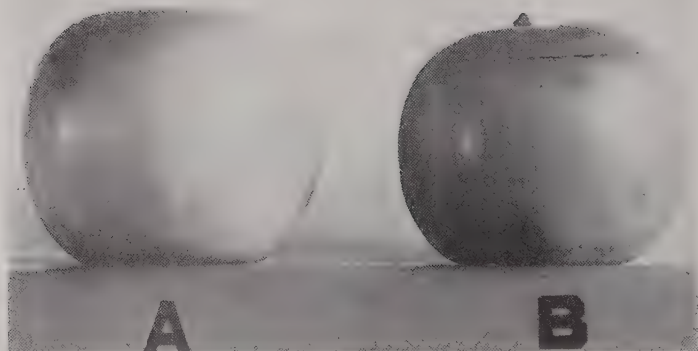


Fig. 7. Typical Grimes photographed January 10, 1918, showing results of immediate storage, (A), as compared with delayed storage, (B).

Under Iowa conditions it is impracticable to let the latest winter apples remain on trees in the fall as long as the above results suggest.

With Sheriff and Mammoth Black Twig, as much color should be allowed to develop as possible before picking. Red color does not develop on apples after picking.

As far as studied, delayed storage is most important with varieties such as Grimes, Sheriff, and Mammoth Black Twig. The fact that these varieties drop badly when allowed to mature on the trees, makes delayed storage practical. No date can be set for the picking of Grimes. The common practice is to pick this variety just before it starts dropping and store in open containers in the packing shed for a week or so before packing, thus allowing the apples to become mature and to change from green to yellow in color. The grower is usually capable of judging when the fruit has obtained its best size. At this time, the green on the side of the apple exposed to the sun has just commenced to shade into a pale yellow on a few specimens. It is advisable to pack the apples in barrels or boxes immediately after picking as fruit allowed to remain in crates soon becomes dusty. The grower must be guided largely by experience in putting this delayed-storage method into practice. There is danger that the apples may become over-mature, a condition which makes the fruit quite susceptible to scald and also shortens its life in storage.

EFFECT OF METHODS OF STORAGE ON SCALD.

During 1913 it was noticed that Mammoth Black Twig picked October 2, somewhat immature, and stored immediately, showed

a decided tendency to scald in cold storage, whereas this same variety stored by several growers of the vicinity in their common cellar storage houses had developed only a slight amount of scald by late winter. This raised the question as to whether it is better to store Mammoth Black Twig in cellar storage than in cold storage.

For two seasons the method of putting the apples into cold storage for six weeks during the warm fall weather and then after settled cold weather set in, placing them for the remainder of the season in common storage under temperatures approximating those of cold storage, has been compared with the methods of continuous cold storage and continuous common storage thru-out the season. The data as presented in table VII show results with from four to six boxes each in cold and in common storage and two boxes stored first in cold storage for six weeks and then placed in common storage for the remainder of the season.

TABLE VII. EFFECT OF METHODS OF STORAGE ON SCALD.

	Sheriff			Mammoth Black Twig		
	Percent of Total Scald			Percent of Total Scald		
	Cold Storage 32°F.	6 Weeks Cold Storage Common Storage*	Common Storage*	Cold Storage 32°F.	6 Weeks Cold Storage Common Storage*	Common Storage*
1913-14	72.5		82.4	26.7		22.2
1914-15				82.3		83.5
1915-16	67.8			85.0		37.3
1916-17	49.9	76.4	84.7	98.5	96.7	95.3
1917-18	10.0	39.0	16.8	78.9	87.0	93.0

*Cellar storage temperatures ranged from 45° to 52°F. for October and November; 35° to 40°F. until March 1st, and averaged around 45° toward last of the season.

The Sheriff apples in every season scalded the most under common-storage conditions. The Mammoth Black Twig were variable, scalding more in cold storage one season and more in common storage the next. Apples stored six weeks in cold storage before being placed in common storage developed an intermediate amount of scald more than in cold storage and less than or as much as in common storage.

RESULTS WITH GRIMES AND MAMMOTH BLACK TWIG, 1917-18.

In 1917-18 six boxes of Grimes and three boxes of Mammoth Black Twig apples were placed in common-storage houses at the orchards of W. S. Keeline, Council Bluffs; W. P. Campbell,

Woodbine; C. H. Deur, Missouri Valley, and with Supt. Max E. Witte, M. D., at the State Hospital, Clarinda, Iowa. The temperatures of these houses were recorded on thermographs. The temperatures were fairly uniform in all of them, running between 40° and 50°F. up to January and between 32° and 40°F. from January to March. In all cases more scald developed on these than on similar lots of apples placed in cold storage at 32°F.

During the fall it is difficult to cool down the common-storage house as early as desirable before placing fruit in storage. The object in storing apples six weeks in cold storage and then removing them to common storage was to determine whether a pre-cooling of the fruit for six weeks would have a beneficial effect on the control of scald. The experiments indicate that this practice has no advantage over storing fruit directly in common storage.

The results in the season of 1913-14, when Mammoth Black Twig apples scalded quite badly in cold storage and yet kept without scalding in common storage, did not hold true in the following seasons. It is possible that the difference in maturity of the apples observed in the season of 1913-14 accounts for the better-keeping quality displayed by the apples in common storage that season.

In all of the work Mammoth Black Twig has developed a large amount of scald under all storage conditions by the last of March. This is a late-keeping variety and with exception of scalding it stands up well under all storage conditions. However, because it scalds readily, it is advisable to sell it earlier in the winter.

The results of this work indicate that Sheriff and Mammoth Black Twig can be stored with only fair success in common-storage houses. While in general well-ventilated caves or houses that are kept moist so that the fruit is not liable to shrink, may give quite satisfactory results for the small grower, for the large commercial growers cold storage is unhesitatingly recommended.

CONTROL OF CERTAIN APPLE ROTS IN STORAGE:

Other diseases than apple scald are often found on stored apples. The losses which they cause to growers, dealers and consumers may become very serious, especially towards the latter part of the storage season. Much of this loss may be eliminated by right methods of harvesting, packing, handling and storing.

Excellent opportunities have been afforded during the course of the cold-storage investigations reported in the preceding pages, to observe the appearance and development of various kinds of apple rots. Following are brief notes on these observations.

ALTERNARIA ROT FOLLOWING SCALD.

During the season of 1917-18, a black fungous growth devel-

oped on the badly-scalded portions of different varieties of apples. Numerous plate cultures of this fungus developed in practically every case an *Alternaria* rot. (fig. 8.) This fungus was noticed on Grimes, Northwestern Greening, Pewaukee, Sheriff, and Mammoth Black Twig. In every case it was found to follow scald.

One box of Grimes, 175 size, was wrapped and stored October 6, 1917, in a room where the temperature was fluctuated between 32° and 40°F. An examination March 28, 1918, showed 47 apples, or 26.8 pct. of the box, infected with *Alternaria* rot. A box of 150 Sheriff which had been stored at 40°F., when exam-



Fig. 8 A and B. A—Upper illustration—*Alternaria* rot on Northwestern Greening. B—Lower illustration—Dry brown rot on Jonathan.

ined June 1, 1918, showed nearly 60 pct. infection with this trouble.

Grimes, Sheriff and Mammoth Black Twig apples stored at 32° and 40°F. were selected for further investigation. Equal lots of each variety were examined and a record made of the number of apples affected with *Alternaria* rot under each of the two temperatures. (Table VIII.)

TABLE VIII. EFFECT OF TEMPERATURE ON ALTERNARIA ROT.

Variety Examined	Date	40°F.	32°F.
Grimes -----	Feb. 12	8.2% rotted	.51
Sheriff -----	Apr. 23	2.2	.49
Mammoth Black Twig -----	Apr. 30	Few	None

These tests indicate that the storage temperature is one of the most important factors in the development of rots. So far as they go they are in harmony with the results of Brooks and Cooley (4) who found that the fungous rot, *Pencillium expansum*, made very little growth at 0°C. (32°F.) and a maximum growth at 20°C. (68°F.). A higher temperature than this checked its growth.

Altho the *Alternaria* rot developed quite extensively after February 1 on Northwestern Greening, and after March 1 on Sheriff, very little of it was noticed during the normal storage period for these varieties.

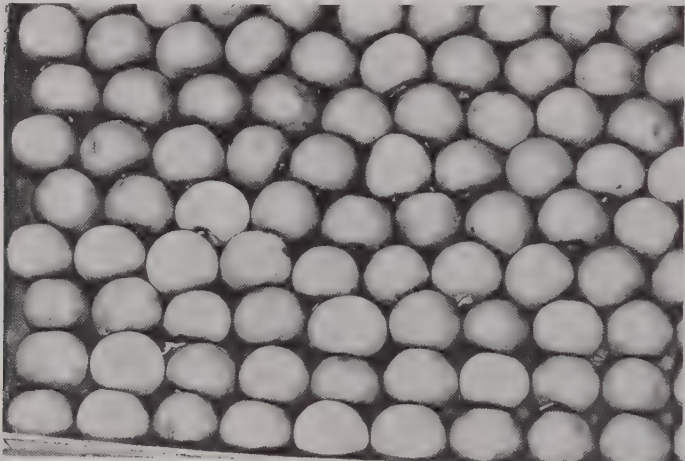


Fig. 9. Small Northwestern Greening, Size 188 per box, harvested and stored same as large size shown in fig. 10.

The fact that apples which show scald are more susceptible to the attack of rots than perfectly sound fruit, emphasizes the great importance of keeping apples from developing scald.

RELATION OF SIZE OF APPLES TO SUSCEPTIBILITY TO ROT.

The largest apples of some varieties, especially Northwestern Greening, are not especially good keepers. For one reason, they have a tendency to check around the lenticles, basin or cavity, thus affording excellent resting places for rot spores and an entrance for their germination tubes into the fruit.

A comparison of fig. 9, showing the smaller size, with fig. 10, which shows the larger size, well illustrates the influence of size on the keeping quality of Northwestern Greenings.

The apples shown were picked and packed, September 18, 1914, and stored September 24, 1914. They were held in cold storage at a temperature of 32°F. until February 16, 1915, and then removed to cellar storage until February 26, when they were examined and photographed.

The small apples shown are very free from decay while the large apples suffered serious injury by the *Alternaria* rot.

AN UNIDENTIFIED BROWN DRY ROT.

The author has had under observation in these investigations an unidentified dry brown rot which as far as he has been able to learn has not hitherto been described. It has appeared on both



Fig. 10. Large Northwestern Greening, size 80 per box, picked and packed September 18, stored September 24, and photographed February 16, same as small size shown in fig. 9. Note difference in susceptibility to rots.

Jonathan and Northwestern Greening, developing sunken areas as shown in the accompanying illustration. (fig. 8B.) These areas are of varying size and outline. The skin becomes a clear brown color, varying from a medium to a rather light tone. The skin remains unbroken. The flesh beneath becomes dry and brown, or brownish, to a depth of from one-eighth to one-fourth inch. All attempts of the author to isolate a causal parasitic or saprophytic organism from the affected tissue have thus far failed.

This rot was called to the attention of I. E. Melhus, chief of the plant pathology section, and he was supplied with material for identification of the trouble. Thus far it has not been identified. It is a trouble concerning which inquiry is being made by those who are interested in handling apples in storage. The writer is unable to suggest what conditions bring it on, nor can he indicate at present any method by which it may be avoided.

SOFT ROT.

The most common, and generally the most destructive, rots found on apples in storage are soft rots caused by species of blue mold (*Penicillium*). These are saprophytic fungi. Generally, they gain entrance into the apple thru some break in the skin. They are distinguished from other rots by the masses of blue-green spore bodies which they develop in the rotting tissue.

SUMMARY OF METHODS OF DISEASE CONTROL.

The losses in storage from apple rots may be practically eliminated by methods which we would briefly summarize as follows:

1. Prevention of attacks of codling moth and other insects, and of apple scab and other diseases in the orchard. This may be accomplished by proper spraying.

2. Care in harvesting the apples and in handling them when grading and packing. Avoid not only bruises, but even the slightest skin breaks or punctures. Avoid pulling out the stem and thereby leaving an opening thru which disease may enter the fruit.

3. Grade carefully all fruit which is to go into storage. Too much emphasis cannot be laid upon the importance of this point. Worm holes, mechanical breaking of the skin, apple scab, scald and other diseases, all open the way for the entrance of fruit-destroying organisms. Store only fruit that has a perfectly sound skin.

4. Keep the fruit itself at a constant low temperature. Experience will show to what extent the room temperature may fluctuate without affecting the temperature of the fruit itself.

5. Remove fruit from storage before the storage season for that particular variety naturally closes. It is recognized that the

length of this period varies somewhat with the same variety in different seasons, and according to the locality or region in which the fruit has been grown.

B. CHANGES OF TEMPERATURE IN COLD-STORED APPLES.

RATE OF COOLING OF COLD-STORED APPLES.

The rate of cooling of fruit after it has been packed and put under refrigeration and the length of time required to cool the inside of the fruit are factors of great importance in determining successful methods of fruit transportation and storage.

Powell (9) in 1905 made important investigations on the pre-cooling of fruit for transportation. The fruit was loaded into a refrigerator car and by the use of fans a forced draft of air at a temperature of 32°F. was blown from a cold-storage house thru the car and back again to the house. Altho a powerful air current was used, it required from thirty to fifty hours to cool the fruit in the center of the package down to 40°F.

The air around the fruit may be cooled quickly, but the package and its contents give up their heat slowly. Under the most favorable conditions in a cold-storage warehouse the fruit in the center of a tight barrel of Bartlett pears stored at a constant temperature of 30°F. may not cool to that temperature within four to seven days if the fruit is about 80°F. when picked, while similar fruit in a 20-pound box or in a slat bushel crate may reach 32°F. in from 12 to 24 hours.

A fruit wrapper retards the cooling. There may be a difference of 10° in temperature of the fruit at the end of one day between a 40-pound box of unwrapped fruit and a 40-pound box of wrapped fruit.

Beach and Eustace (2) studied the rate of cooling air and fruit in different styles of packages in cold-storage warehouses. They found that for fruit stored in a storage room held at 34°F. it took 32 hours longer to reduce the temperature of paper-wrapped fruit in the center of a slat crate from 80° to 36°F. than to reduce similar unwrapped fruit from 78.5° to 35°F. In the center of a standard box it took 12 hours longer to reduce the temperature of the paper-wrapped apples from 79° to 36°F. than to reduce similar unwrapped apples from 77.5° to 35°F.

There was less difference with the fruit in barrels. At the end of 74 hours the unwrapped fruit in barrels dropped to 38.5°F. while similar wrapped fruit dropped to 43°F.

The unwrapped fruit in slat crate dropped to 35°F. in 34 hours and in a bushel box in 58 hours, while the wrapped fruit in

slat crate dropped to 36°F. in 66 hours, and in a bushel box in 70 hours.

FLUCTUATION OF TEMPERATURE OF FRUIT STORED IN PACKAGES

When apples packed in either boxes or barrels are placed in cold storage their temperature is eventually reduced until it approaches that of the storage room. If the temperature of the room fluctuates, the temperature of the apples inside the packages naturally tends to fluctuate also, but to a lesser degree.

Further work was undertaken by Greene at the Iowa station with the crop of 1915 for the purpose of getting additional data as to length of time required for apples in the center of a box or barrel in cold storage to reach room temperature, but more particularly to study the fluctuation of the temperature of the fruit inside of boxes or barrels following fluctuation in storage-room temperatures; observations were also made on the effect of wrapping the fruit on the amount and rapidity of changes in its temperature.

Northwestern Greening was selected for these experiments. The fruit was picked and packed at the normal harvest season for the variety and immediately stored at 32°F. Later the fruit was brought into a warm room, unpacked and held there until its temperature reached 70°F. It was then repacked in boxes and barrels, each having the tube of a metal-resistance thermograph placed in the center of the package. The apples in certain boxes were wrapped with ordinary apple wraps; all other fruit went into the package unwrapped. The fruit was then returned to cold storage under a temperature averaging about 32°F. but which actually fluctuated between 28°F. and 36°F.

WRAPPED BOX APPLES AND UNWRAPPED BARREL APPLES.

As would be expected, the temperature of the barreled fruit did not drop quite as fast as that of the boxed fruit. The curve of the range of temperatures of the barreled fruit, however, followed quite closely the temperature curve of the boxed fruit, especially after the first 70 hours. (fig. 11.) It should be borne in mind that the records taken were for temperature at the center of these packages and that the fruit towards the outside approximated storage-room temperatures sooner than did the fruit in the middle of the package.

In a storage room approximating 32°F. it required 30 hours for the temperature in the center of the box to drop from 70° to 40°F., and an additional 130 hours to reduce the temperature in the center of the box to 34°F. In other words, the temperature in the box dropped 30 degrees during the first 30 hours and but 6 degrees in the next 130 hours.

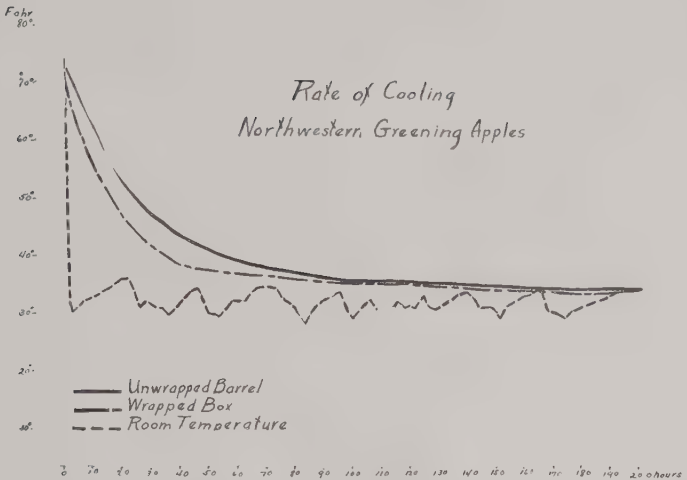


Fig. 11. Graph showing rate of cooling of wrapped box as compared with unwrapped barrel of Northwestern Greening.

WRAPPED AND UNWRAPPED BOX APPLES.

A comparison of the changes in temperature of wrapped and unwrapped fruit, each packed in standard apple boxes, shows that the unwrapped apples at first approached room temperature more quickly than did the wrapped apples, but when both had dropped as low as 37°F. the temperature of the wrapped apples continued to fall while that of the unwrapped fruit remained practically stationary. The curve of these temperatures is shown in fig. 12.

As previously mentioned, it appears that inclosing the apples in wrappers has a tendency to prevent the air next to the fruit from following the fluctuations in the room temperatures. Under the conditions of this experiment it actually caused the continued lowering of the temperature of the fruit itself, while the unwrapped fruit remained almost stationary in temperature.

This experiment was later varied by introducing very great fluctuations in the room temperatures as shown by the curves in fig. 12. After the fruit had been stored about 110 hours, the room temperature was suddenly raised above 65°F., then suddenly dropped below 35°F., then again raised above 65°F., and then again dropped below 35°F., then again raised above 60°F. The sudden rise in room temperature was followed by a rise in the temperatures of both the wrapped and the unwrapped fruit, the unwrapped responding much more readily to the change than

did the wrapped fruit. When the temperature of the room was suddenly lowered, the rise in temperatures of the fruit was soon checked and lowered. Under continued great fluctuations in room temperatures, it was shown that the unwrapped apples followed the changes in temperature sooner and to a greater degree than did the wrapped apples.

These tests show that inclosing the fruit in wraps results in noticeably neutralizing the effect of sudden fluctuations in the storage-room temperatures on the temperature of the fruit.

UNWRAPPED BOX AND BARREL FRUIT COMPARED.

Another investigation compared the changes in temperature at

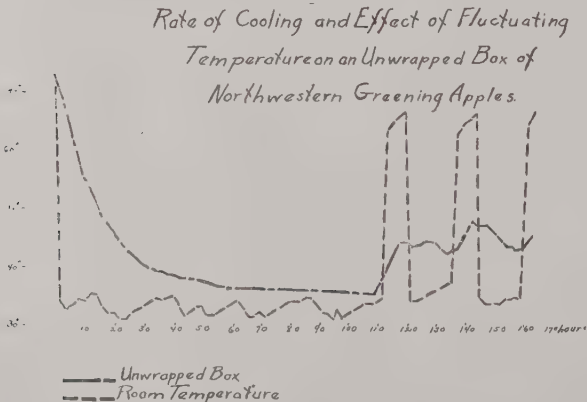
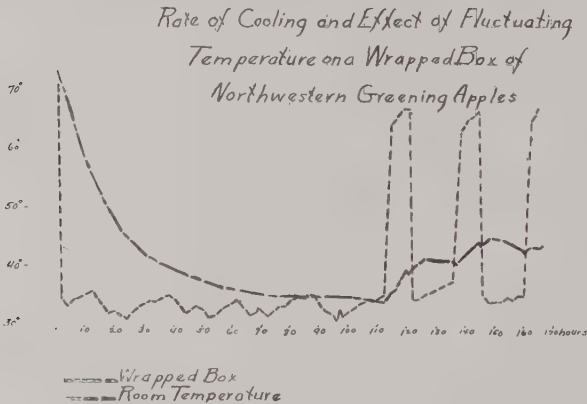


Fig. 12. Temperature curves for (A) wrapped and (B) unwrapped boxes of Northwestern Greening going into cold storage and with later fluctuations of storage room temperatures.

the centers of unwrapped box and unwrapped barrel apples. The temperature of the room in which the apples were stored was fluctuated every five or ten hours for 70 hours with the number of degrees of change ranging from $28\frac{1}{2}$ to 46 degrees, without affecting the temperature at the inside of the barrel or box of apples. (See fig. 13.) The temperature of the barrel was held at 36°F. and the box at 35°F. thruout the period of fluctuating temperatures mentioned above. At the end of 70 hours the temperature of the room was lowered 50 degrees, to 5°F. , for one hour and then gradually brought up to 14°F. during the next four hours. The temperature at the center of the barrel dropped to 34°F. , a lowering of 2° , and the temperature of the box dropped to 33°F. , a lowering of 2° . The temperature of the room was then raised to 77°F. in two hours. The temperature at the center of the barrel immediately jumped up to 35° , a one-degree rise in temperature, but the box continued to go down another degree during the first hour until it reached 32°F. and was not affected by the rise in room temperature until the second hour, when it again rose to 33°F.

During the next 20 hours, the room temperature was dropped to 62°F. for a few hours, then raised to 77°F. again. The fruit in the box continued a steady rise in temperature from 33°F. until it reached 46°F. , whereas the fruit in the barrel dropped down a degree when the temperature of the room was dropped to 62°F. , and rose to 45°F. when the room was raised to 77°F.

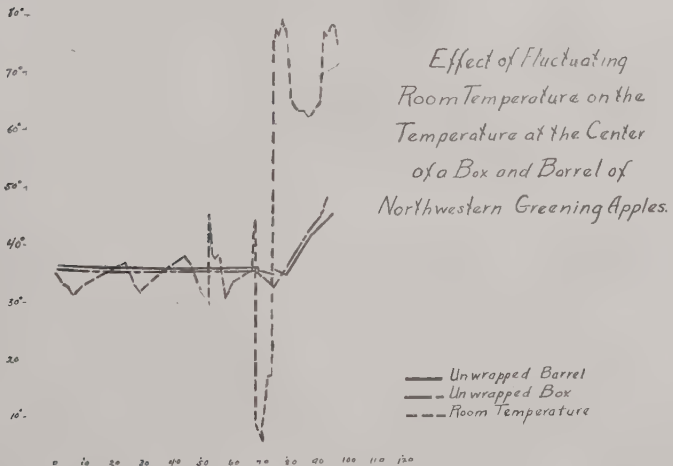


Fig. 13. Curve showing effect of fluctuation of storage room temperatures on temperature of fruit at center of a box and a barrel of Northwestern Greening apples.

From these tests it appears that extreme changes of 10 to 15 degrees in room temperature for a short time do not change the temperature at the center of a package of fruit. While extreme changes of from 30 to 40 degrees for a short time affect the temperature of the fruit but slightly, if they are continued over five or six hours, undoubtedly they would cause considerable change in the temperature of the fruit.

GENERAL DISCUSSION OF TESTS WITH FLUCTUATING TEMPERATURES.

Our investigations and the experiments of others show clearly that these are among the conditions which are essential in order to successfully store fruit:

1. Apples keep best at a temperature of 32°F.
2. After picking from the tree, apples ripen rapidly unless stored at a low temperature in cold storage. Thus when the fruit is ready for storage, it should be cooled to 32°F. as quickly as possible.
3. A low initial temperature of the storage room when the fruit is first placed in cold storage is necessary if the fruit is to be cooled to 32°F. at once.
4. Avoid high temperature because it hastens ripening and consequently shortens the life of the apple in cold storage.

During the harvesting season there are details which are quite important. One of these is the disposition of the fruit after picking. Picked apples should not be exposed to the sun either in the orchard or in the packing shed, as they absorb considerable heat. A study of the time and temperature required to cool the apples when first placed in cold storage demonstrates that apples which have absorbed heat during the day do not cool off readily at night, even tho the nights are comparatively cool.

C. FINAL SUMMARY.

1. Temperature is a very important factor in the control of apple scald and of other more common diseases of apples in cold storage.
2. A constant storage temperature not higher than 32°F. in these experiments has given the best control of these diseases.
3. The drier the storage rooms the less the scald. Less scald has developed in a relative humidity of from 60 to 70 pct., than in one of from 80 to 90 pct.
4. The degree of humidity bears some relation to the development of apple scald but the degree of temperature has a greater influence.
5. Wrapping apples in paper delays the appearance of scald during storage. An apple wrapper of paraffine paper retards

scald more than the ordinary paper apple wrapper, but this difference is slight and of no practical importance from the commercial standpoint.

6. No correlation has been found between the size of the apples and the amount of scald developing on them in storage. The fact that some variations are found suggests the question whether these variations may not be due to differences in degree of maturity between large and small apples picked at the same time.

7. The right degree of maturity of apples when they are put into cold storage is the prime consideration in the control of apple scald.

8. Immature fruit scalds readily in storage. Whatever the variety of apples under consideration, it is in the best condition for cold storage when it has reached prime maturity for picking, is well colored, hard-ripe, and neither immature nor over-mature.

9. Under Iowa conditions, on account of danger of freezes or premature dropping, it is not always practicable to let the crop stay on the trees until it reaches prime maturity for picking. In such cases it is best to delay cold storing and hold the fruit at ordinary temperatures until it more nearly reaches the best or optimum degree of maturity for cold storing. This is often the case with Grimes, Mammoth Black Twig (ARKANSAS) and Winesap.

10. Apples of best or optimum maturity for cold storing will scald more quickly in common than in cold storage.

11. The best maturity for cold storage is not always the best for common storage.

12. Iowa-grown Mammoth Black Twig and Sheriff apples can be stored with only fair success in common storage houses. Let them get as much red color as possible before picking. While in general well-ventilated caves or houses that are kept moist so that the fruit is not liable to shrink, may give fairly satisfactory results for the small grower, for the large commercial growers of these varieties cold storage is unhesitatingly recommended.

13. Apple scald makes fruit more susceptible to the entrance of rot fungi. *Alternaria* rot, which is a black fungous growth, develops readily on the badly-scalded portions of the fruit and hastens decay.

14. The largest apples are generally attacked more quickly by rots in storage than smaller apples of the same variety, other things being equal.

15. Low temperatures around 32°F. are best to check the growth of rots in storage.

16. It requires 30 to 60 hours to reduce the temperature of fruit in the center of a box or barrel from a temperature around 70°F. down to 35°F.

17. The temperature of apples in boxes may be reduced sooner than that of apples in barrels.

18. Unwrapped apples packed in boxes are more quickly affected by changes in storage temperature than similar wrapped apples.

19. Small changes in room temperatures do not materially change the temperature of fruit in the package, particularly of wrapped fruit. This suggests the question as to whether this fact can be taken advantage of by the practical cold-storage man to reduce the cost of operation.

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EXPERIMENT STATION COLD-STORAGE PLANT.

In a critical investigation of methods for the control or prevention of diseases of apples in cold storage, the storage rooms must be held constantly under accurate temperature control. If this is not done it is impossible to determine how much the results of the experiments may have been modified by variations in the storage-room temperatures.

In the earlier investigations at the Iowa agricultural experiment station of problems pertaining to the cold storage of apples, one of the experiment station cold-storage rooms was assigned for this work. It was soon found to be unsuitable because of lack of satisfactory control of the refrigeration. Consequently its use for this special purpose was abandoned and the work from 1906 to 1915 was carried on wholly thru co-operation with commercial cold-storage plants located in different parts of the state.

Since 1915 refrigeration rooms have been available in the building in which the pomology section rooms are now located. The temperatures are held constant by automatically controlled apparatus, which requires comparatively little supervision. The motive power is furnished by an electric current. The refrigeration machine is one of the Audiffren-Singrum type. By its use it has been possible to secure the temperatures desired in the investigations and maintain them constantly under accurate control for the entire period of the experiment, even thru periods when it has been impractical to give the apparatus constant supervision.

The arrangement of this machine is shown in fig. 14. It consists of a shaft carrying at one end a drum (A), at its center another drum (B), and at its opposite end a pulley (C), for revolving it. Its appearance is practically that of a large dumbbell and when it is in operation, its end drum (A) is partially immersed in the brine to be cooled, and the other drum (B) is immersed in a similar tank containing flowing water which acts as a cooling agent for the drum and for the compressor pumps contained within the drum.

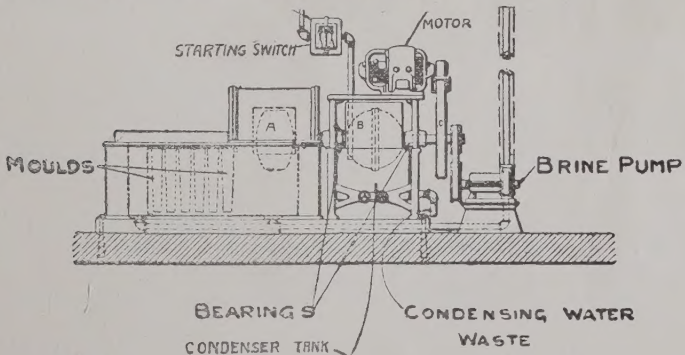


Fig. 14. Vertical cross section of refrigeration machine.

The machine operates on the compression system, using sulphur dioxide as its refrigerating agent. The compressor pumps are suspended from a steel band which operates on an eccentric fastened to the shaft within the drum (B), and are held in a vertical position by a lead counterweight. The pressure limit is determined automatically by the action of the counterweight.

When the machine was constructed the air in the dumbbell was entirely exhausted, and a charge of sulphur dioxide and pure neutral oil admitted, after which the dumbbell was hermetically sealed. The working parts are thus constantly oiled, preventing metal to metal contact. Oxidation of the lubricating oil cannot occur as there is no oxygen present.

The sulphur dioxide gas is compressed in the drum (B) and on coming in contact with the cool surface of the drum which is suspended in cold water, it condenses to a liquid. The liquid sulphur dioxide passes thru a double hollow shaft to the drum (A), where it comes in contact with the surfaces of the drum which is revolving in the brine tank. The brine has a much higher temperature than the liquid sulphur dioxide. Sulphur dioxide has a very low boiling point and vaporizes readily under these conditions. In the process of vaporization the sulphur dioxide absorbs the heat from the brine thru the bronze shell of the drum, thus cooling the brine. After vaporizing, the sulphur dioxide is sucked back to drum (B), thru the double hollow shaft of the dumbbell, thus completing the cycle. The cool brine is pumped thru the pipes in the cold-storage rooms by means of a circular brine pump.

The cold-storage plant consists of six storage rooms of varying sizes with capacities ranging from 20 to 60 boxes of apples. One of the larger rooms has four small compartments opening into it on one side, each of which holds four apple boxes and is equipped with individual automatic temperature control.

The temperatures in the rooms and compartments may be controlled either by the use of automatic electrical thermostats which operate solenoid valves, or by the use of hand valves. The temperature is regulated by the flow of the cold brine thru the refrigerating coils. The temperature of the brine itself is controlled by means of a thermostat attached to the return brine pipe. This thermostat operates the electrical controller which starts and stops the refrigeration machine. In this way automatic control of the temperatures is secured thruout the plant and personal supervision reduced to a minimum.